PANGS OF SCIENCE

by

Philip Handler
President
National Academy of Sciences

Commencement Address

The Ohio State University
Columbus, Ohio

March 16, 1978

According to legend, Prometheus, who pitied the sad estate of mortals, defied the will of Zeus and stole fire from the sun in order to give that gift of power which made possible man the toolmaker, the traveler and food grower. Prometheus was condemned to torture and the gods on Olympus schemed to prevent mankind from fully possessing the fruits of its growing power. To this end, they created Pandora whom they endowed with Aphrodite's beauty, Hermes' gift of persuasion and Apollo's music to entice the heart of man. Endowed also with burning curiosity, inevitably she pried into the box which she had been sternly forbidden to open, a box which, once opened, could not be closed. And thence escaped a thousand plagues to scourge hapless humankind until only hope remained. The fact that Prometheus and Pandora are part of the same legend constitutes a great truth.

We have long gloried in the power that Prometheus gave us and came to assume that science and science-based technologies offered endless opportunity to alleviate the condition of man. But for the last decade, Pandora has increasingly claimed our attention as we became aware that technology can also engender unanticipated secondary "dysbenefits." The tragedy of Prometheus was not his defiance of the gods but his inability to foresee the full spread of consequences, leaving us, therefore, the children of Pandora.

For several decades, scientists, who pursued science for the pure joy of it, publicly associated science with spectacular technological progress. We found it facile to justify government support of basic research on the ground that it is the indispensable substratum of technological innovation, hence automatically to be taken as a public good. For having thus claimed credit for the benefits of technology when the public regarded technology as desirable and benign, science

is now held, by some, to be responsible for the evils of technology grown out of control, independent of democratic accountability. The claim of science to autonomy is seen as a claim for the autonomy of technology, for allowing technology also to develop according to its own logic. Science, as an institution, is sporadically attacked by those who denounce it as the expensive pastime of academics who show insufficient concern for efficiency and profitability, and by those who see it as the instrument of military and economic domination. Both political right and left demand that scientists should concern themselves more with the short term "real needs" of society, although themselves perceiving these needs quite differently.

Only yesterday, scientific activity could flourish innocently, unconscious of its role in processes that sometimes result in disastrous effects. Today, the movement called "technology assessment" demands that both science and technology prove their innocense in advance.

If the stream of anti-science pronouncements calling for a return to instinct, spontaneity, and "nature" were merely a literary revival of anti-intellectualism, the indictment would have little more effect than when science was the target of such mystic, romantic critics as Blake and Ruskin, even though it is hard to forget that anti-intellectualism also nurtured the worst political movements of this century. What is new in the present situation is that criticism of science no longer comes exclusively from outside. Numbers of scientists now join other intellectuals and the man on the street in voicing anxiety.

Pasteur spoke of laboratories as "temples of the future and of well being," and said that "... in those laboratories man learns how to read the works of nature, works of progress and universal harmony, whereas his own works are too often acts of barbarism, fanaticism and destruction." But the works of science are now seen by a vocal few to operate as much in the service of barbarism as in that of universal harmony.

The ground was laid long ago. André Malraux traced it back to the use of poison gas in World War I which, he said, "for the first time showed the adverse side of science's balance sheet." That was 30 years before Oppenheimer's famous statement that, "Physics has now known sin." What was not perceptible earlier was the discomfort which would arise from the fact that, as its pursuit became increasingly expensive, science has associated itself increasingly with the authority and power of the State. The scientist must live with an inescapable ambiguity: science claims to be an end in itself but it is recognized and supported by society only because of its instrumentality.

Nothing so illuminates that transformation as the cases of Galileo and Oppenheimer. The former was a conflict between two different concepts of the nature and limits of knowledge, scientific analysis versus that which is alien to it, whereas in the latter, technical advice to the state was at odds with the political decision which it was called upon to inform.

Despite those changing circumstances, most scientists, nevertheless, "stick to their lasts." Indifferent to the conflicts others perceive in the relationship between science and the state, they pursue science at the frontiers of their disciplines; and it is they who advance those frontiers, enlarge our horizons and provide mankind with the means to create a better tomorrow.

At the same time, a few scientists give us pause by evoking recourse to moral and aesthetic values which must be preserved if science and civilization are to survive. But please understand that the same values have led scientists to both sides of current debate concerning appropriate public policy for such matters as protection of the environment, nuclear power, and research on recombinant DNA. Some attempt examination of such matters by formal risk/ or cost/benefit analysis. But the environmental problems of our day involve risks and benefits that usually accrue to different groups, and costs, risks and benefits that are incommensurable. Costs

are reckoned in dollars; benefits in aesthetic or material values; risks in human lives. Risk/benefit analysis can certainly inform the decision maker, but decision necessarily continues to turn on value judgments; the acceptability of a given level of risk remains a political, not a scientific question. When scientists fail to recognize these boundaries, unspoken political beliefs easily becloud seemingly scientific debate.

And that is my principal message. The malaise in the scientific community arises from confusion of the role of scientist qua scientist with that of scientist as citizen, confusion of the ethical code of the scientist with the obligation of the citizen, blurring, therefore, of the distinction between intrinsically scientific and intrinsically political questions. In the mind of a scientist, there need be no conflict between science and human progress. The ethos of the scientist is easily summarized: intellectual integrity and objectivity; informed skepticism that welcomes

reevaluation of seemingly established doctrine; tolerance and respect for the views of others; readiness to admit ignorance or error; dedication to the advancement of understanding of the universe; and identification with the world collectivity of scientists so engaged. Unfortunately, that ethos, which should compel the behavior of the scientist in weighing the social value of specific technologies, ~~Unfortunately, that~~ can be warped when suffused with a social or political ideology. The scientist-advocate can, unconsciously, become a partisan. In the words of Maurice Arthus, "Blinded by his passion, he has recourse to all means to defend it, for to him, all means have become legitimate."

We find this process illustrated almost daily. Science, sometimes damned as culprit because it was progenitor of the technologies whose unregulated use has despoiled field, stream and atmosphere also affords the principal means for recognition of such problems and planning their management. Witness the sophisticated science required for recognition of phosphate

as the cause of eutrophication of lakes and streams, for identification of invisible, unsmellable constituents of automobile exhausts as the cause of smog; of sulfate aerosols as the probable principal hazard to public health from air pollution; of freons as a possible cause of increased skin cancer due to photochemical processes in the stratosphere; consider the science underlying concern for the possible effect on climate of a build up of CO_2 in the atmosphere due to fossil fuel combustion. Thus science, the progenitor of technology also provides its conscience.

What seems lost on some who would participate in this process, particularly with respect to environmental carcinogens, is that the necessity for scientific rigor is even greater when scientific evidence is being offered as the basis for formulation of public policy than when it is being offered to find its way in the marketplace of accepted scientific understanding. Science itself can benefit and progress by early publication of properly documented preliminary findings;

public policy may not rest on observations so preliminary that they could not find acceptance for publication in an edited scientific journal.

Political decision-makers have no choice but to rely on the validity of what seems to them to be a recondite form of science, thereby placing a heavy onus on scientists who engage in such activity. Recent experience indicates that the political process had best move slowly and allow ample opportunity for predictive hypotheses and preliminary observations to be thoroughly examined and tested before acting upon them.

When, for example, evidence of adverse effects on humans is lacking, I could wish that students of carcinogenesis would refrain from ~~publication~~ announcements until they have completed a sufficient series of coherent studies to enable rational discussion, rather than announcing each experiment in turn, generating public alarm that can neither be justified nor assuaged. Once a compound has been publicly called into question, decision

concerning its use becomes unavoidable. The sensible guide would be to accept substantial hazard only for large benefit, little hazard for small benefit, and no hazard if it can be avoided without penalty. But in most cases, to date, quantitative assessment of risk is entirely lacking. Hence, conservative value judgments, minimizing the possibility of risk, must prevail, as they have.

For most environmental pollutants that have been called to attention, we are concerned with potential but as yet undemonstrated hazard. Statistically speaking, relatively few persons have been known actually to have been seriously damaged by man-made chemicals.

We have become highly conscious of such problems; a host of institutions, public and private, are alert and vigilant. The result has been a stream of regulations, each well intentioned, most, indeed commendable. But in the absence of persuasive data concerning the magnitude of risk, if any, to humans, the sum of such regulation can engender public

cynicism, ensnarl life in the workplace, stifle innovation, and slowly paralyze the economic life of the nation. Hence, I applaud the evolution of The Clean Air Act, from mandatory reduction of risk to zero, regardless of cost, to decision based on comparison of marginal cost with the marginal benefit of pollution abatement. But that returns to the scientific community the burden to quantify the risk and relate health effects to exposure levels. We shall need more science -- not less. A decade ago it was desirable to flag public attention to potential hazards and proceed as if each hazard were a clear and present danger. It is time to return to the ethics and norms of science so that the political process may proceed with greater confidence. Admittedly, that is not easy. At the current stage of scientific understanding of almost every matter where science and technology impact public policy, decision must be taken in the face of uncertainty. The public may wonder at why we don't already know that which appears vital to decision -- but science will retain its place in public opinion only if

we steadfastly admit the magnitude of our uncertainty and assert the need for further research. And we shall lose that place if we dissemble or argue as if all necessary fact and information is in hand -- whether the question be dietary prevention of atherosclerosis, the health effects of air pollution, or the economics of solar energy. Scientists best serve public policy by living within the ethics of science, not those of politics.

The controversy surrounding nuclear power has been conducted on both sides by scientists who have done much to inform that debate. Technical issues that have not been resolved to the satisfaction of some scientific critics include: the effectiveness of technical means for preventing diversion, by governments, of weapons-usable materials from the fuel cycle, or their theft by terrorists; the safety aspects of reactor design including protection against the consequences of deliberate sabotage; the long-term management of nuclear wastes and the release of long-lived radioactive effluents from fuel reprocessing plants. Presumably, generally acceptable solutions to these questions will ultimately emerge. My point is that, even when they do, debate will continue and the scientific community, like the country generally, will remain divided precisely because the true issues are not intrinsically scientific questions but social and political values. It is important that all of us recognize the distinction.

The risk associated with the nuclear fuel cycle for light-water reactors is estimated as approximately 1/200th that associated with an equivalent electrical supply generated by coal combustion. But these figures are not strictly comparable. The estimate for nuclear power is the statistically prorated effect of the loss of life in large accidents postulated to occur with very low frequency in many reactors over a long period. No such event has yet occurred. We hope none will. Apart from the possibility of such major events, the death rate due to nuclear power appears to be essentially zero. Controversy, therefore, centers about the appropriate public approach to the rare major accident. An accident, once in a thousand years, that would result in a thousand fatalities could be stated to subject society to the risk of loss of one person per year -- trivial as compared to crossing streets, eating steak, or taking baths. But some view the possibility of a large-consequence accident, however low its

probability, as intrinsically unacceptable. How society should weigh rare catastrophic events in comparison with guaranteed frequent small events cannot be settled by any objective criterion known to me. And scientists should not debate this as if it were a scientific question.

Public distrust of the management of nuclear energy programs in the past will cast a long shadow into the future. Even granting that there can be developed essentially acceptable technical solutions to the problems of reactor safety, waste management and the safeguarding of weapons-usable materials, many will question whether human institutions can be relied upon to implement and monitor them on a long-term basis; many will be skeptical that international institutions for the management of the nuclear fuel cycle will provide sufficient assurance against the proliferation of nuclear weapons.

To these judgments must be added valid concern for the future of a democratic society if the safeguarding of nuclear

facilities will perpetually require rigorous security measures. That prospect has led to proposals for minimization of the numbers of such vulnerable facilities by construction of well-guarded, self-contained power parks or islands each to contain a considerable number of reactors, a commensurate reprocessing plant and waste disposal facilities, so as to minimize the intrusion of the necessary security measures on the rest of society.

For many, their view of the desirable character of future society conditions their rejection of nuclear power. They see nuclear power as the most visible symbol of centrally managed technology for which the average citizen has surrendered control to bureaucratic experts who cannot be held accountable. Some of the younger public dislike nuclear power because it offers the likelihood of continuation of a high-growth, materialistic society that, in their view, will ultimately prove disastrous to both the physical and social environment of man. Espousing decentralization, local self-sufficiency and small-scale enterprises controlled by

consumers and craftsmen, the positive symbols of this school are household solar energy, windmills, and renewable resources, generally. These are all legitimate social and political questions; their debate must not be permitted to distort objective evaluations of safety, economics or technical performance.

Whether breeder reactors will prove imperative to the secure future of America will turn on yet other factors: agreement to international control of the fuel cycle, the success of conservation in damping demand for electricity, the magnitude of oil and gas fields yet to be found, the success of tertiary oil recovery, the economic feasibility of various coal technologies and the rate of 'penetration' of diverse other presently uneconomical energy technologies.

How the turbulent transition from the age of hydrocarbons to the age of essentially infinitely available energy resources will turn out depends on whether we can muster the political will to do all that is required, particularly to mount and sustain the necessary R&D program. We will need

all the science we can muster to support development of benign new technologies to enable the nation wisely to choose among truly feasible and economic alternatives, and not be in the hapless position of merely rejecting unacceptable technologies.

We have little understanding of the factors that prompted the extraordinary acceleration of science in Europe, particularly England, two centuries ago and no more understanding of the subtle circumstances that caused the technological torch to move from Europe to America a century ago. But we do know that we live in an overpopulated, competitive, interdependent world that we no longer dominate and that many another once powerful, prosperous dominant civilization has disappeared. Our dynamic society may be less resilient than we have thought; hence, there can be no greater error than to allow sociopolitical values to distort or cover truth.

The attack on science as progenitor of technology has also spawned an attack on science itself, viz., on research in genetics, particularly that utilizing recombinant DNA, the technique in which a fragment of the genetic material of one species is inserted into that of a second species. This simple technique, the most powerful tool now available for illuminating the structure and functioning of the genetic apparatus, evoked a crescendo of concern, which is now diminishing somewhat.

The earliest expressed concern was for the possibility that in the course of such research there might be generated a microorganism which would escape laboratory control and, being of a new species, might prove to be dangerous to man, to domestic animals or to the environment. Since first the matter arose, I have had difficulty in imagining that this research could engender any risk greater than that which is daily accepted by those who minister to persons afflicted with genuine viral or bacterial infection. I have difficulty in

believing that a small fragment of DNA or of a harmless virus placed in an innocuous bacterium can transform it into a raging beast, unmanageable by standard cautious laboratory procedure. And there is absolutely no contrary evidence.

A panel of the Academy that examined this question concluded that:

> "The body of evidence acquired...over the the last few years clearly indicates that recombinant DNA research, performed under the NIH guidelines, presents no real risk to public health...
>
> "Indeed, it is probable that most recombinant DNA work using enfeebled E. coli systems could be carried out safely without any special precautions."

Ironically, the very enzymic 'cut and paste' procedures used in the laboratory have been found to occur constantly in nature, with plasmids moving back and forth among unrelated bacterial species and being remodeled by identical mechanisms. Accordingly, Elwell and Falkow were led to state that, "While committees of scientists and laymen banter about recombinant DNA

around conference tables, Nature has been conducting experiments prohibited under the NIH guidelines for recombinant DNA research." It boggles my mind that committees of the Congress are seriously debating bills to regulate this field of research, to protect us from a hazard whose existence cannot be demonstrated.

Some who publicly raise concerns for safety of such research may harbor a hidden agenda. Some consider that man should not knowingly intervene in the workings of biological evolution; others that this research could be a major step along a trail that could lead to the capability of genetic manipulation of man himself. Both agree that it would be best to halt all possibly contributing research at its earliest stage, viz., all research with recombinant DNA. Their position is that as soon as a scientist can see some direct pathway from his present work to an evil outcome at some future date, no matter how remote, he should abandon the field. That distinguished immunologist, Sir Macfarlane Burnett, said, "It is a hard thing for an experimental scientist

to accept, but it is becoming all too evident that there are dangers in knowing what should not be known."

To Dr. Burnett I reply that it must be far more dangerous to live in ignorance than to live with knowledge. He forgets that the uses of science are indeed unpredictable. He ignores the intrinsic value of knowledge of our own genetic mechanisms, the immediately obvious practical applications of research in this field and the applications which must lie beyond the horizon of our imaginations. Conversely, the ugly possibility which concerns him could occur only at the end of a long and extraordinarily difficult experimental road and in full view of many observers. There will be ample opportunity to prevent the feared outcome, whereas termination of the entire enterprise at this stage denies to posterity all of its potential fruit.

Nor can I easily condone any abridgement of the freedom of scientific inquiry. Historically, freedom of inquiry--like freedom of speech, of religion, of the press and of assembly--came to be cherished precisely as the scientific search

for truth freed mankind from dogmatic religious and political thought. Scientific inquiry has challenged the dogma of an authoritarian world for the last 400 years. It has freed men's minds as it eased their toil. It was Thomas Jefferson who said, "There is no truth on earth that I fear to be known." Abridgement of the freedom of inquiry of scientists, therefore, could constitute the first step along a trail which must inevitably lead to loss of those other freedoms that we cherish.

Neither law nor tradition confer an absolute right of freedom from all restraints. We have readily accepted various such with respect to scientific inquiry, as for example, those regarding the use of human subjects. But we need accept no constraints other than those found absolutely essential to protect against injury other values that we cherish. To use the power of government for the suppression of ideas that might otherwise flow from research would take us back to an era of dogmatism from which mankind has only recently escaped. But it would be a feckless course. In the long run it is impossible to stand

in the way of the exploration of truth. Someone will learn somewhere, sometime.

The optimists among scientists, myself included, see the further development of scientific understanding as a worthy goal in itself and as the means for expanding the planet's energy resource base, for converting nonrenewable resources into an infinite resource base, for minimizing human pain and disease, as a means of so managing affairs that the goal of an equitable, harmonious world need not be denied to mankind. But the path is perilous. Success demands an endless stream of greater and lesser appropriate decisions, with little forgiveness for error. The scope of human choice and freedom widens at the same time that the possible price of error escalates. I regret that, vaguely sensing this circumstance, public attitudes seem to be shifting from seeking means of accomplishing the greatest possible good to settling for pathways that risk the least harm. Let us hope that human

institutions are not so frail as to deny us the realization of the opportunities which lie within our intellectual and moral capacities. For we can be unabashedly optimistic concerning the prospects for continuing great discoveries in science. Consider only two fields, astronomy and biology.

For millennia, human experience of the heavens was limited to that revealed to us by radiation in that portion of the electromagnetic spectrum to which our retina is sensitive. For only a few years, sensors on the ground and in space have explored earth's surround as 'seen' in the gamma ray, X-ray, ultraviolet, infrared and radio portions of the spectrum. The image thus revealed stretches the human imagination as has no other vision in history. And patently the best is yet to come. I can hardly wait for the large space telescope to be placed in orbit!

It is difficult to communicate the excitement or the dimensions of the current explosion of biological understanding: understanding of metabolic regulatory mechanisms, of the

structure and function of cell membranes, of genetic mechanisms and their defects, of the nature of the cell surface, of how cells communicate with other cells. Neurobiologists, faced with the seemingly hopeless task of dealing with an overwhelmingly complicated circuitry without a wiring diagram, now have quantitative understanding of the mechanism of the nervous impulse, of the connection between nerve cell and nerve cell, or end organ, knowledge of activators and inhibitors, and awareness that the brain is an essentially endocrine tissue. Understanding of the brain is suddenly perceived as an inevitably successful rather than as an impossible task. There has never been a time like it. Moreover, we stand on the brink of understanding the mechanisms of diverse diseases, understanding that will surely permit us better to cope with some of our oldest afflictions.

Our current malaise, then, stems in considerable part from a few bad experiences and from the time delay in meeting the high hopes and expectations raised in the minds of those

who appreciate the great power of science, and the force of technology. Those expectations have taken on a new light as science has also revealed the true condition of man on earth. I see no alternative but to address vigorously the principal questions of science itself, and to use our ever-widening understanding and evermore sophisticated technology with grace and charity and wisdom, recognizing that there will always be questions to be asked and problems to be managed if not solved.

We are not omnipotent but neither are we unwitting foils of powerful forces over which we have no control. To be sure, new problems seem always to arise as we solve old ones. But we have learned not to seek a perfect world. Our joy must be found in those acts by which we exercise our unique human capabilities to eradicate what we abhor and to promote that which we value and cherish. For myself, I retain my faith that science, which has revealed the most awesome and profound beauty we have yet beheld, is also the principal tool that our civilization has developed to mitigate the condition of man. You see, science is the hope in Pandora's box.

Thank you